PHENIX

Measurement of J/ψ Production in Proton–Proton Collisions by the PHENIX Experiment

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Outline

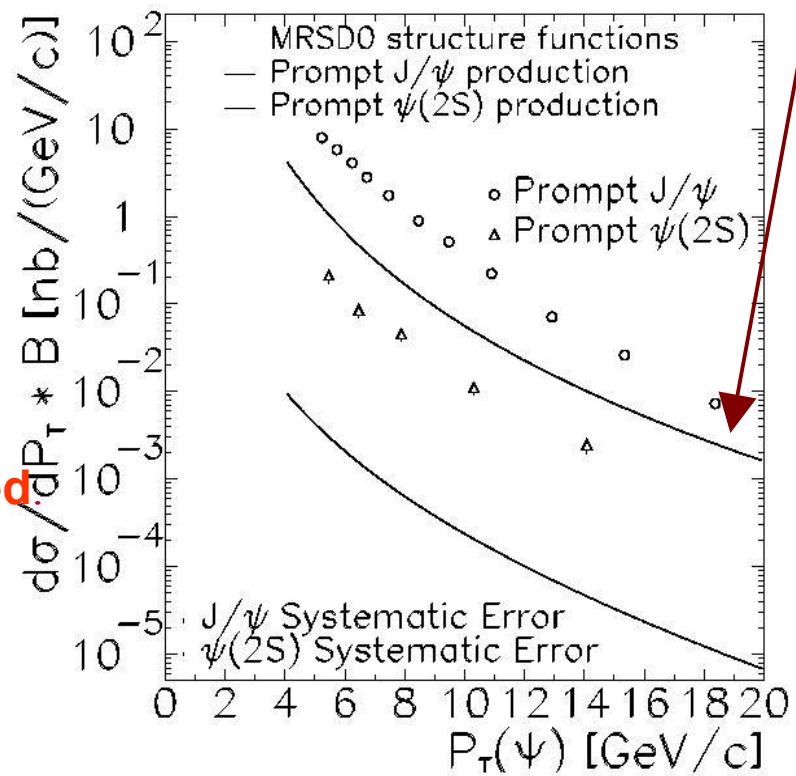
Results from PHENIX for $pp \rightarrow J/\psi$ at $\sqrt{s} = 200$ GeV will be presented.

- Why is this measurement important?
- RHIC and the PHENIX detector
- Analysis procedure
- Results for $pp \rightarrow J/\psi$ Production
- Conclusion and Outlook

Motivation: Understanding J/ψ Production Mechanisms

- Fixed target data have provided J/ψ σ_{TOTAL} and $\langle p_T \rangle$ for $\sqrt{s}$ = 7-38.8 GeV
- Results from collider energies have raised interest in various models:
  - Color Singlet Model
  - Color Octet Model (NRQCD)
  - Color Evaporation Model (phenomenological)
  - ***Systematic studies at RHIC energies with wide η and p_T coverage are needed.***

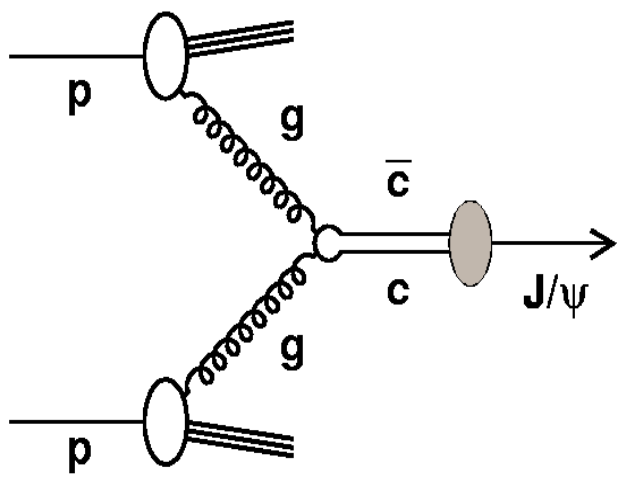
CDF J/ψ cross section is greater than Color Singlet Model prediction PRL **79** 572 (1997)



Charmonium production in hadron-hadron collisions

- Charmonium production in a hadron-hadron collision includes
  - Production of a $c\bar{c}$ pair (perturbative QCD calculation is applied)
  - Hadronization of the pair into a charmonium (non-perturbative QCD phenomenon) → not clearly understood yet
    - Color-evaporation model
    - Color-singlet model
    - Color-octet model (NRQCD)

Gluon fusion is dominant



$$\sigma(pp \to \psi X) = \iint dx_1 dx_2 g(x_1, Q) g(x_2, Q) \sigma(gg \to \psi)$$

$$\sigma(gg \to \psi) = \sigma(gg \to c\bar{c}) P(c\bar{c} \to \psi)$$

$\sigma_{J/\psi}$ (absolute value)

- **Absolute normalization for $\sigma_{J/\psi}$ is sensitive to production model**
  - Color-evaporation model (CEM)

    can explain $\sigma_{J/\psi}$ using $\rho_{J/\psi}$ (fraction of J/ψ to all produced $c\bar{c}$ pairs) ~ 0.06 determined by photo-production data
  - Color-singlet model (CSM)

    Color singlet production underestimate $\sigma_{J/\psi}$ by a large (~10) factor
  - Color-octet model (COM)

    Consistent using the color octet matrix element $\langle O^{J/\psi}_8(^1S_0)\rangle + 7/M_c^2 \langle O^{J/\psi}_8(^3P_0)\rangle = 0.02$ GeV^3 from photo-production data, but has large uncertainties from
    - Extraction of color-octet matrix element
    - Charm quark mass
    - Factorization and renormalization scales

J/ψ Measurements at RHIC-PHENIX

- Better understanding of Quantum Chromo-dynamics (QCD)

  charmonium production includes
  - ✓ perturbative QCD aspects
  - ✓ non-perturbative QCD aspects

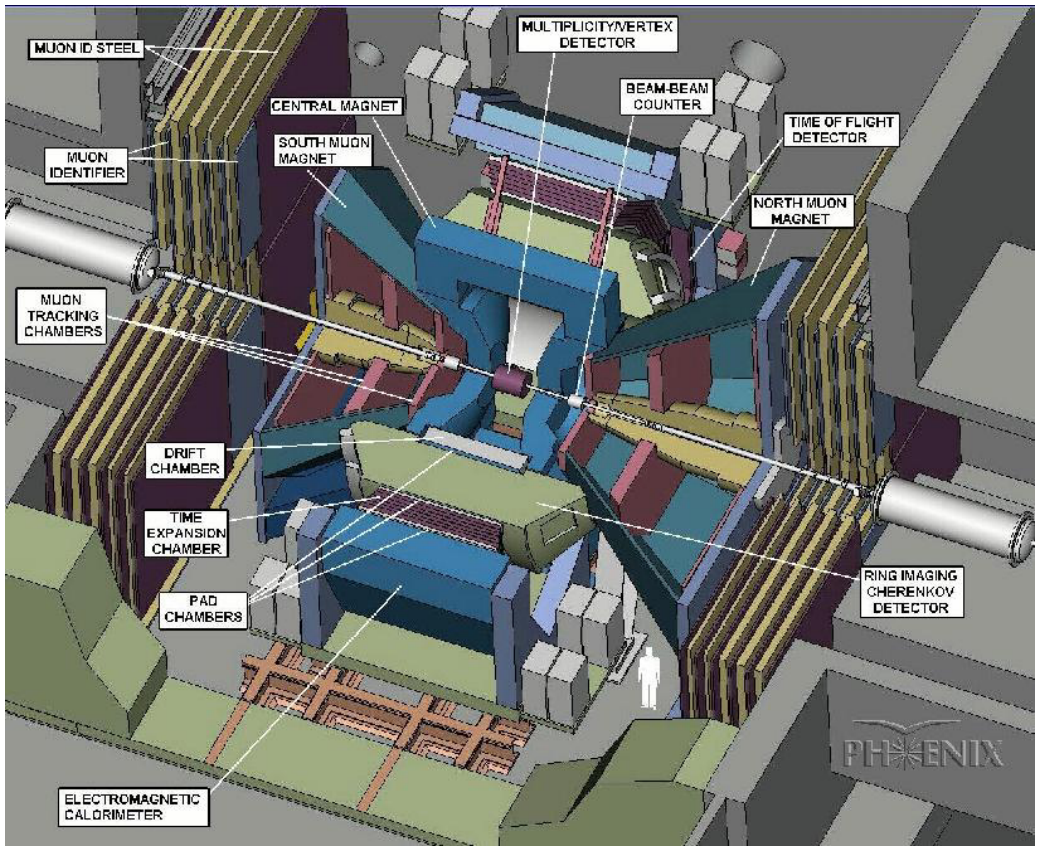
  Cross sections
  Polarization
  Relative yields (χ/ψ etc)

  In wide energy range

- Probe for new physics at RHIC
  - QGP physics with heavy-ion collisions at highest energy
    ($(\sqrt{s_{NN}})_{max}$ = 200 GeV for Au+Au)
    - pA: "normal nucleus effects"
    - AA: "medium effects"
  - Spin physics with polarized p+p collisions at highest energy
    ($\sqrt{s_{max}}$ = 500 GeV)

(Un-polarized) p+p data are important as reference

The PHENIX Detector



- ***e***, γ, ***h*** **(Central Arms)**
  - $|\eta| < 0.35$, $\Delta\varphi = \pi$
  - $p_T > 0.2$ GeV/*c* (charged particles)
- **μ (Muon Arms)**
  - $1.2 < |\eta| < 2.4$, $\Delta\varphi = 2\pi$
  - $p_{tot} > 2$ GeV/*c*
- **Interaction-trigger and vertex Detectors**
  - **Beam-Beam Counters** ($3.0 < |\eta| < 3.9$)
  - **Zero-Degree Calorimeters** ($|\eta| > 6.2$)
  - **Normalization Trigger Counters** ($1.1 < |\eta| < 2.8$)

Independent measurements of J/ψ using both e^+e^- channel and $\mu^+\mu^-$ channel

Acceptance at low momentum (p_T) combined with wide rapidity coverage → enables the extraction of the total production cross-section at the highest energy

RHIC Run Summary

Run	Species	$\sqrt{s_{NN}}$ (GeV)	Integrated luminosity	Arms in operation
Run-1(2000)	Au+Au	130	1.0 mb^{-1}	W+E
Run-2(2001-2002)	Au+Au	200	24 mb^{-1}	**W+E+S**
	p+p	**200**	**150 nb^{-1}**	
Run-3(2002-2003)	d+Au	200	2.7 nb^{-1}	**W+E+S +N**
	p+p	**200**	**350 nb^{-1}**	

This poster

Analysis : Run2

$$\frac{\mathbf{B_{ll}}\, d^2\sigma}{dydpT} = \frac{N_{J/\psi}}{\int L dt\ \Delta y \Delta p_T} \frac{1}{\varepsilon_{lvl1}\varepsilon_{minbias}} \frac{1}{A\varepsilon_{rec}}$$

$\int Ldt$ = **67 nb^{-1}** ($\mu^+\mu^-$) **and 82 nb^{-1}** (e^+e^-) **± 9.6%**

$A\varepsilon_{rec}$ **D** ε_{lvl1} varied for electrons and muons as a function of y and p_T

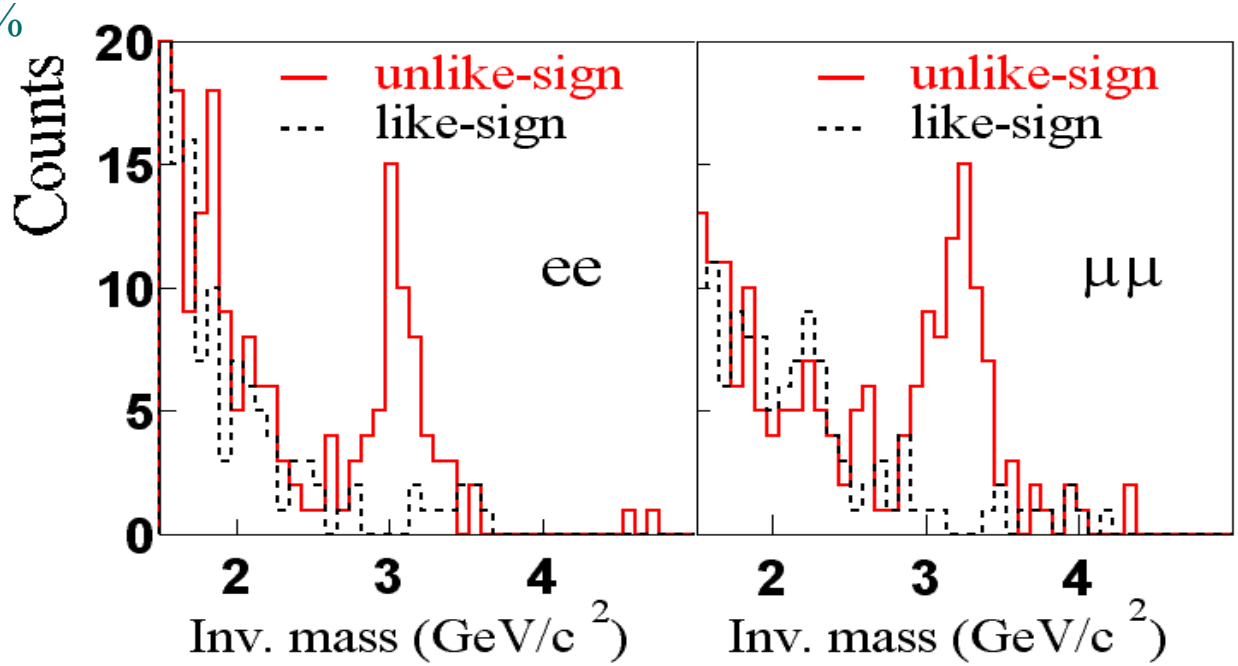
$\mu^+\mu^-$: $A\varepsilon_{rec}$ **x** ε_{lvl1} = 0.038 -0.017 ± 13%

e^+e^-: ε_{lvl1} 2**x**2 = 0.87-0.90 ± 5%, 4**x**4 = 0.30-0.74 ± 36%

e^+e^-: $A\varepsilon_{rec}$ = 0.026-0.010 ± 13%

$\varepsilon_{minbias}$ = 0.75 ± 3%

$N_{J/\psi}$ **is determine by** ***like-sign subtraction***



$d\sigma_{J/\psi}/dp_T$

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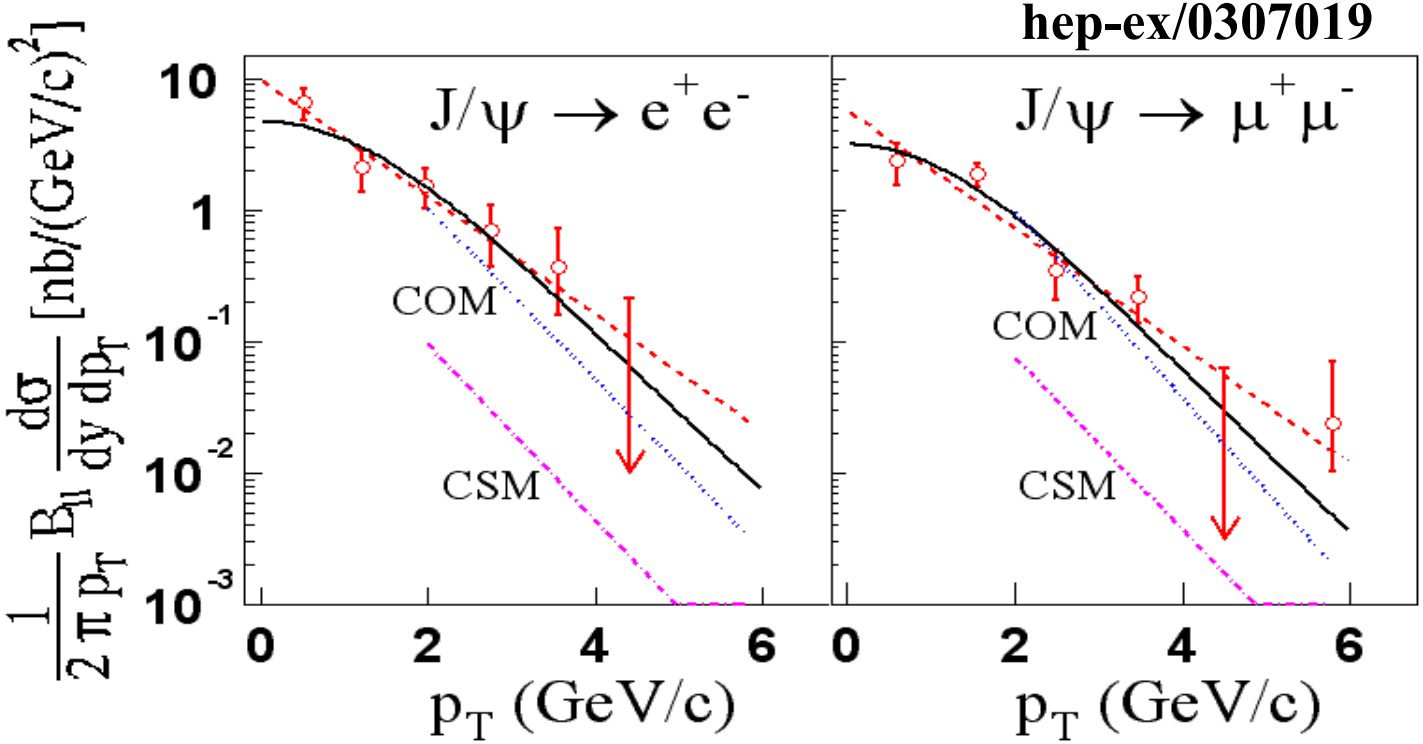
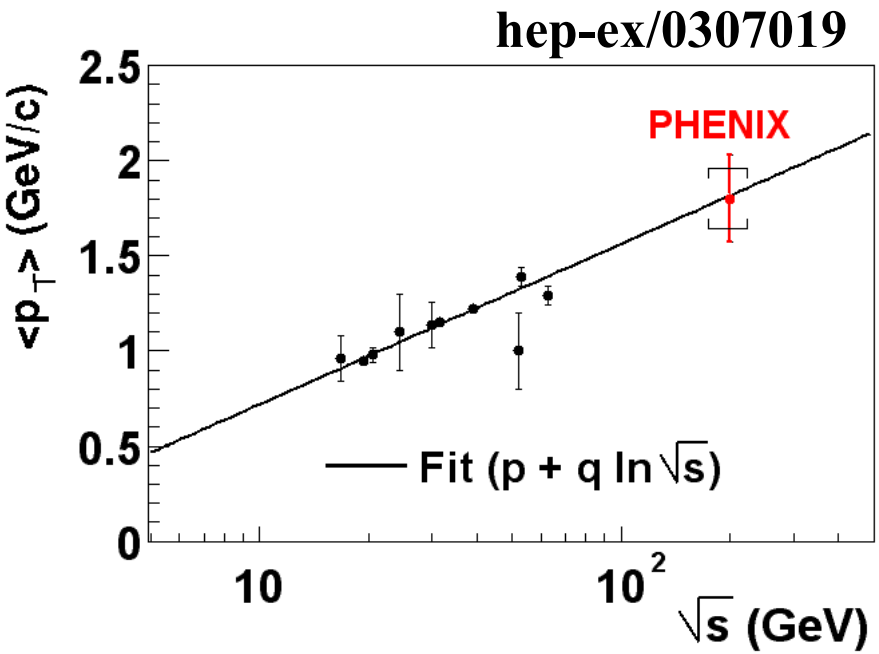


- **Dashed line is an exponential fit.**
  - **Solid line is a fit to $1/(2\pi p_T)\, d\sigma/dpT = A\,(1+(p_T/B)^2)^{-6}$**
    - **(phenomenological fit from fixed target data)**
- Reasonable agreement with NRQCD predictions (+color octet matrix elements)

<p_T>



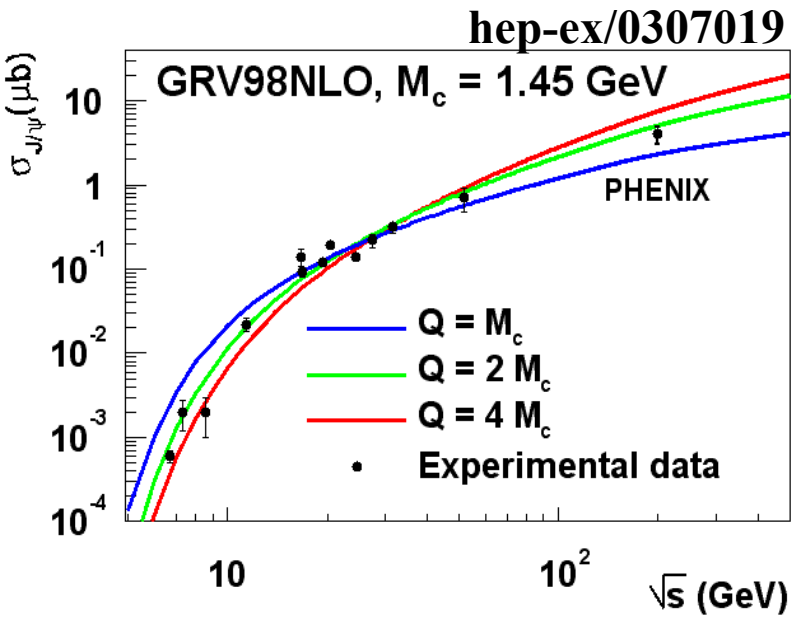
<p_T> = 1.80 ± 0.23 (stat.) ± 0.16 (syst.) GeV/*c*

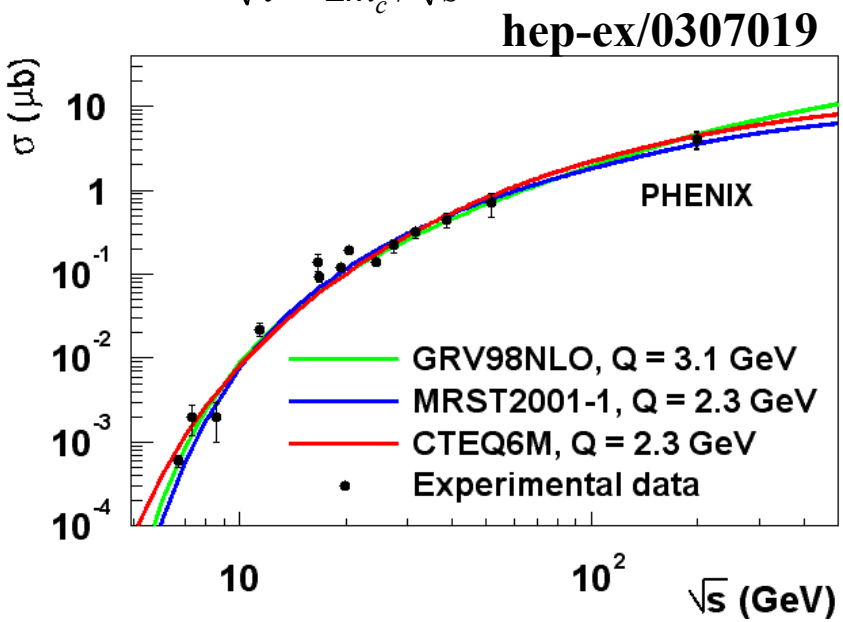
- Average transverse momentum (<p_T>) is slightly higher than lower energy results.
- Energy dependence can well be fitted with a logarithmic function.

$\sigma_{J/\psi}$ ($\sqrt{s}$ dependence)

$$\sigma_{J/\psi}(\sqrt{s}) \propto \int_{\sqrt{\tau}}^{1} \frac{dx}{x} g(x) g(\tau / x)$$

$$\sqrt{\tau} = 2m_c / \sqrt{s}$$

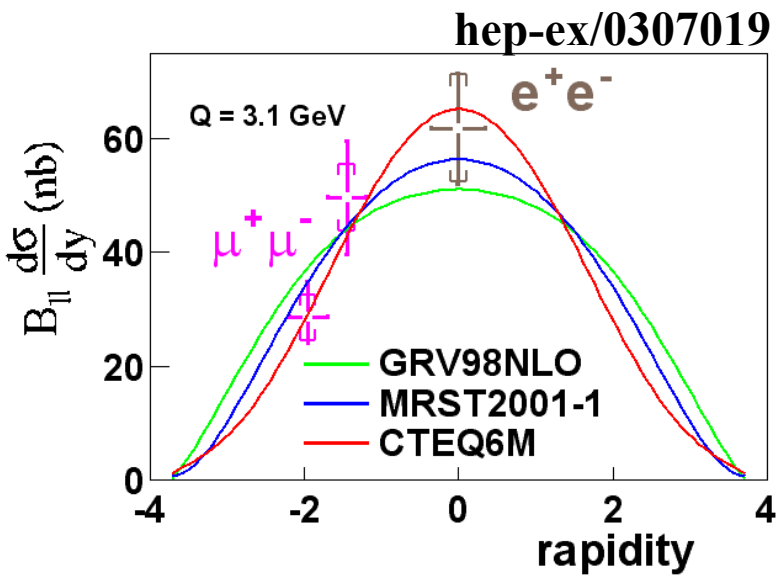


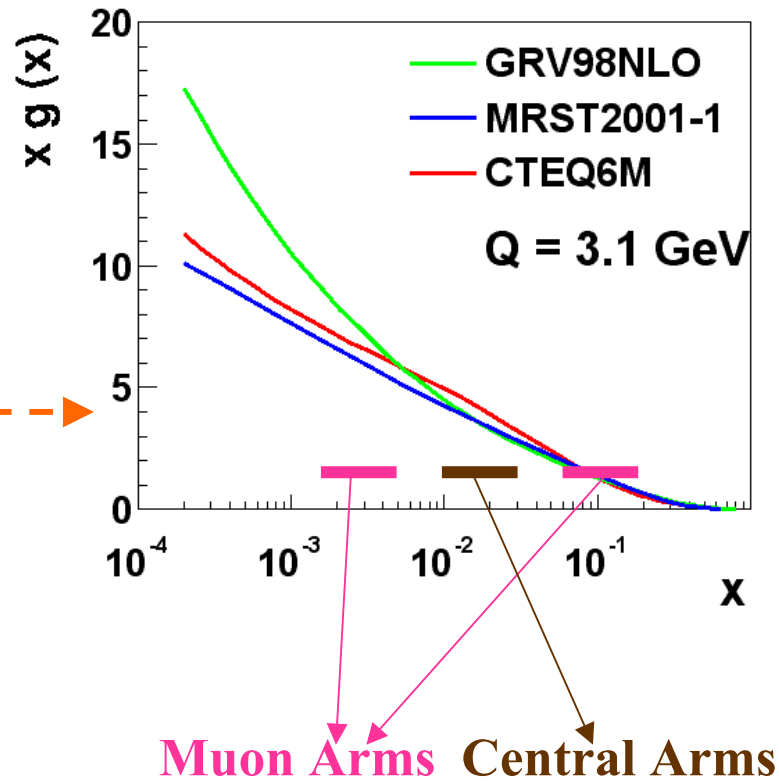


- Energy dependence of $\sigma_{J/\psi}$ is sensitive to **gluon distribution function** and its scale Q
- Our result and lower-energy results are consistent with typical gluon distribution functions with a reasonable choice of $Q \rightarrow$ confirms the gluon fusion picture of J/ψ production in hadron-hadron collisions in a wide energy range

$d\sigma_{J/\psi}/dy$ and $\sigma_{J/\psi}$

$$\frac{d\sigma}{dy} \propto g(x_1)g(x_2),\ x_{1,2} = (2m_c/\sqrt{s})\exp(\pm y)$$





- Rapidity shape is mainly sensitive to **gluon distribution function g(*x*,*Q*)** in the proton and consistent with most of typical PDF sets

Using the curve which describes our data best, total cross section was obtained

$\sigma(p+p \rightarrow J/\psi X) = 3.99 \pm 0.61\ (stat.) \pm 0.58\ (syst.) \pm 0.40\ (abs.)\ \mu b$

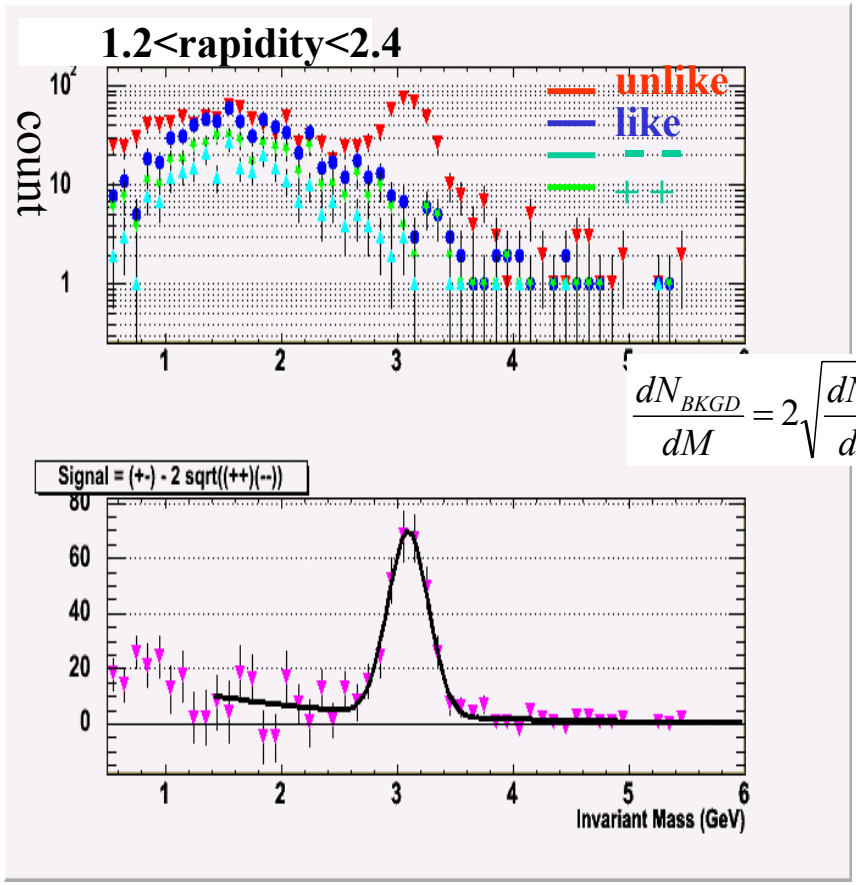
using Br ($J/\psi \rightarrow l^+l^-$) = 0.059

Analysis Run3

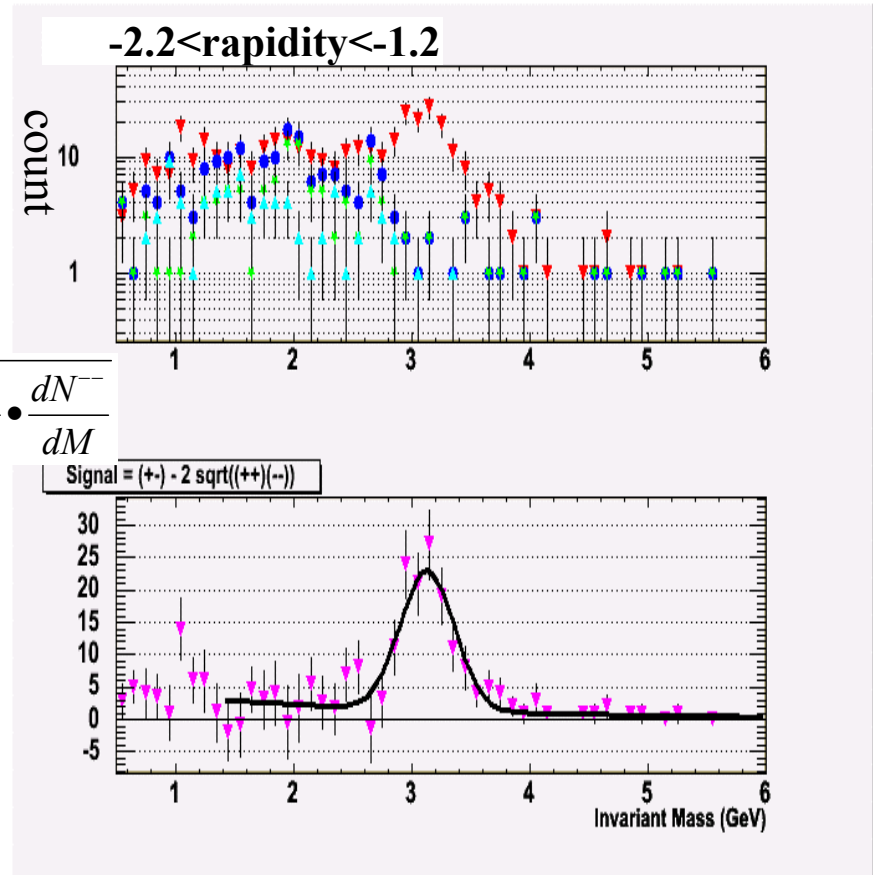
RHIC Run 3

- pp collisions at $\sqrt{s}$ =200 GeV
- 208nb^{-1} used in South $J/\psi \rightarrow \mu^+\mu^-$
- 184nb^{-1} used in North $J/\psi \rightarrow \mu^+\mu^-$

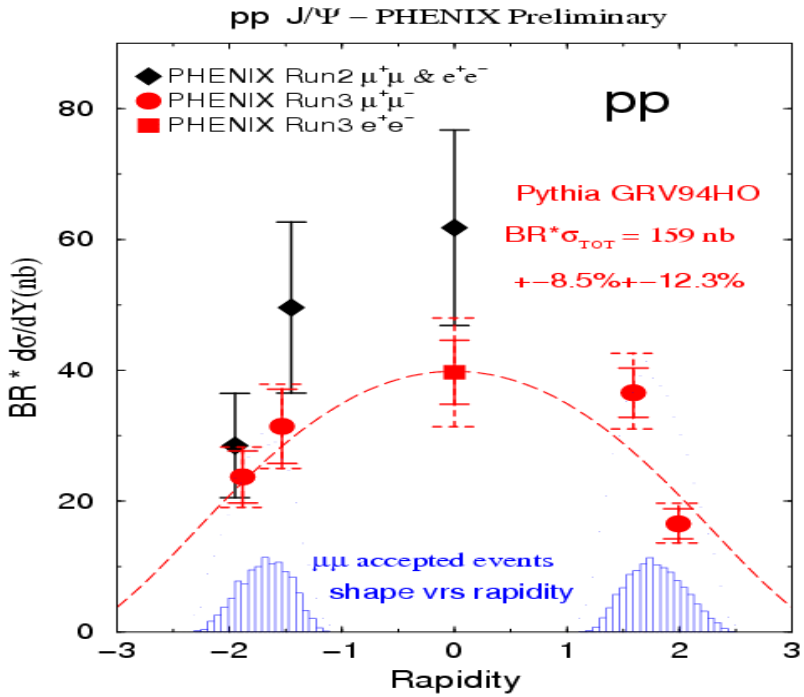
- ✓ **more statistics**
- ✓ improved methods of the chamber efficiency calculation
- ✓ Background subtraction method improved



$$\frac{dN_{BKGD}}{dM} = 2\sqrt{\frac{dN^{++}}{dM} \bullet \frac{dN^{--}}{dM}}$$

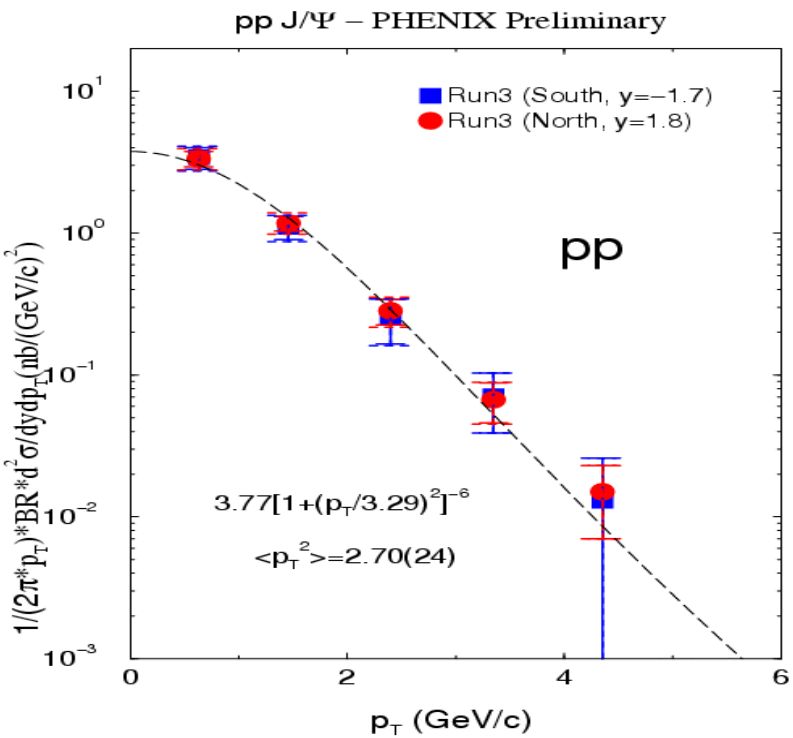


$d\sigma_{J/\psi}/dy$: Run3



- $\sigma_{J/\psi}(p+p \rightarrow J/\psi X) = 2.70 \pm 0.23\ (stat.) \pm 0.33(syst.)\ \mu b$
  using Br $(J/\psi \rightarrow l^+l^-) = 0.059$
- The fit on the plot : Pythia GRV94HO
- Assuming the uncertainties are independent, these two results are consistent each other(mean value : ~1.3 sigma apart)

$d\sigma_{J/\psi}/dp_T$: Run3



- Fit to $1/(2\pi p_T)\, d\sigma/dpT = A\,(1+ (p_T/B)^2)^{-6}$ (phenomenological fit from fixed target data)
- $\langle P_T^2 \rangle = 2.70 \pm 0.24$(stat) GeV/*c* ; A=3.77 , B=3.29

Conclusion and Outlook

- **J/ψ** particles are clearly identified with **PHENIX** with a small background via e^+e^- and $\mu^+\mu^-$ decays in the **p+p** Run at RHIC (Run-2 and Run-3) at $\sqrt{s}$ **= 200 GeV**
- p_T distribution is consistent with Color-Octet Model prediction. Average p_T, $\langle p_T \rangle_{y=1.7} = 1.80 \pm 0.23$ (stat.) $\pm$ 0.16 (syst.) GeV/c is slightly higher than lower energy results.
- Rapidity distribution is consistent with gluon distribution function and total cross section $\sigma_{J/\psi}(\sqrt{s} = 200\ \text{GeV}) = 3.99 \pm 0.61$ (stat.) $\pm$ 0.58 (syst.) $\pm$ 0.40 (abs.) μb was extracted.
- Energy dependence of $\sigma_{J/\psi}$ can be well reproduced by gluon distribution function.
- The absolute normalization for $\sigma_{J/\psi}$ can be reproduced well by the Color-Evaporation Model and the Color-Octet Model.
- The total cross section $\sigma_{J/\psi}(\sqrt{s} = 200\ \text{GeV}) = 2.70 \pm 0.23$ (stat.) $\pm$ 0.33(syst.) μb and average $\langle p^2_T \rangle_{y=1.7,\,1.8} = 2.70 \pm 0.24$(stat.) GeV/$c$ from Run-3 was extracted with more statistics and small systematic uncertainty.
- Run-3 data were used to understand the d+Au data and will give more accurate comparison with the different models which were done with Run-2 data.
- These results are important as reference data for both Au+Au , d+Au and polarized p+p data.